Hilal Singer*[1], Şükrü Özşahin[2]

A Pythagorean Fuzzy Approach to Identify and Prioritize Factors Affecting Import Decisions in Wood Supply Chain

Pitagorin neizraziti pristup za prepoznavanje i određivanje prioritetnih čimbenika koji utječu na odluke o uvozu u lancu opskrbe drvom

ORIGINAL SCIENTIFIC PAPER
Izvorni znanstveni rad
Received – prispjelo: 9. 2. 2024.
Accepted – prihvaćeno: 11. 12. 224.
UDK: 630*88
https://doi.org/10.5552/drvind.2025.0191

ABSTRACT • *Wood is a highly sought-after commodity traded internationally to meet the global demand for building materials, furniture, and paper products. The decision-making process for wood imports is intricate and influenced by various factors. Prioritizing these factors helps decision-makers allocate resources, time, and attention efficiently and make well-informed and strategically effective decisions. This study proposes an interval-valued Pythagorean fuzzy analytic hierarchy process (AHP)-based decision-making framework to identify and analyze factors influencing wood import decisions. With the aim in mind, four main factors are determined: "economic factors", "political factors", "material-related factors", and "market factors". Each main factor has four sub-factors. The interval-valued Pythagorean fuzzy AHP method reveals the weight of each factor based on experts' perspectives. According to the results, the most important main factor is "economic factors". The sub-factors with the highest local importance are: "supply chain and logistics management" in the "economic factors" group, "political stability" in the "political factors" group, "wood species" in the "material-related factors" group, and "demand and demand trends" in the "market factors" group. The global weights show that the most important sub-factors are "supply chain and logistics management", "political stability", and "wood species". The model's robustness is assessed through sensitivity, validity, and comparative analyses, and high stability is observed in the ranking of the factors.*

KEYWORDS: *wood import; analytic hierarchy process; Pythagorean fuzzy set; expert perspective; supply chain*

SAŽETAK • *Drvo je vrlo tražena roba kojom se trguje na međunarodnoj razini kako bi se zadovoljila globalna potražnja za građevnim materijalom, namještajem i proizvodima od papira. Proces donošenja odluka o uvozu drva zamršen je i na nj utječu različiti čimbenici. Određivanje prioritetnih činitelja pomaže donositeljima odluka da učinkovito rasporede resurse, vrijeme i pozornost te da donesu dobro utemeljene i strateški učinkovite odluke. Ova je studija prijedlog okvira odlučivanja utemeljenoga na Pitagorinu neizrazitom analitičkom hijerarhijskom procesu (AHP) s intervalnim vrijednostima za prepoznavanje i analizu utjecaja na odluke o uvozu drva. S tim ci-*

* Corresponding author
[1] Author is researcher at Karadeniz Technical University, Department of Industrial Engineering, Trabzon, Turkey. https://orcid.org/0000-0003-0884-2555
[2] Author is researcher at Karadeniz Technical University, Department of Industrial Engineering, Trabzon, Turkey. https://orcid.org/0000-0001-8216-0048

ljem utvrđene su četiri osnovne skupine utjecajnih čimbenika: ekonomski čimbenici, politički čimbenici, čimbenici povezani s materijalom i tržišni čimbenici. Svaka skupina tih čimbenika ima četiri podčimbenika. Pitagorina neizrazita AHP metoda s intervalnim vrijednostima otkriva važnost svakog čimbenika na temelju stajališta stručnjaka. Prema rezultatima istraživanja, najvažniju skupinu glavnih čimbenika čine ekonomski utjecaji. Podčimbenici s najvećom lokalnom važnosti jesu upravljanje opskrbnim lancem i logistikom u skupini ekonomskih čimbenika, politička stabilnost u skupini političkih čimbenika, vrsta drva u skupini čimbenika povezanih s materijalima te potražnja i trendovi potražnje u skupini tržišnih čimbenika. Globalni ponderi pokazuju da su najvažniji podčimbenici upravljanje opskrbnim lancem i logistikom, politička stabilnost i vrsta drva. Robusnost modela procjenjuje se na temelju osjetljivosti, valjanosti i komparativne analize, a visoka stabilnost uočena je u rangiranju čimbenika.

KLJUČNE RIJEČI: *uvoz drva; analitički hijerarhijski proces; Pitagorin neizraziti skup; stručna perspektiva; opskrbni lanac*

1 INTRODUCTION
1. UVOD

Wood is a highly popular natural material utilized extensively across the globe. Its broad spectrum of applications stems from its strength, aesthetic appeal, durability, ease of processing, and lightweight nature. Wood is commonly used in the construction industry for various purposes such as building frames, flooring, roofing, and walls (De Araujo *et al*., 2016). Additionally, it is extensively used in the furniture industry for manufacturing chairs, tables, and cabinets (Geng *et al*., 2019). The paper industry relies heavily on wood pulp for manufacturing paper products. Wood is also used for decorative purposes such as interior design, sculptures, and handicrafts (Park *et al*., 2010). The global demand for wood has been steadily increasing over the years, driven by population growth, urbanization, and economic development. As a result, the international trade of wood and wood products has risen to meet both domestic and foreign demands (Bit and Banerjee, 2014).

Wood import provides access to wood materials that might not be available in a specific region due to several reasons such as unsuitable climate or lack of resources for growing specific species of trees or limited domestic production capacity. Wood import helps to meet the growing demand for wood products, reduces dependency on a single source of wood, mitigates the risks associated with fluctuations in supply and price, and supports various industries such as construction, furniture making, and paper production (Gültekin *et al*., 2009). Importing wood is a complex process that is influenced by various factors such as cost, quality, and availability (Vu *et al*., 2020). Understanding which factors are most important and prioritizing them accordingly helps decision-makers make more informed and effective choices. By weighing up these factors, organizations can optimize their decision-making processes, reduce risks, and make more strategic decisions about their wood sourcing and supply chain management.

The literature contains several studies examining the purchase and sale of wood and wood products. Arabatzis and Klonaris (2009) evaluated the import demand for different categories of wood and wood products in Greece between 1969 and 2001 using a linear approximation of the quadratic AIDS model. Gültekin *et al*. (2009) identified the capacities and amounts of raw materials purchased by the subsectors of the Turkish forest industry and made demand forecasts for future periods. Limaei *et al*. (2011) detected significant relationships between wood imports and population, gross domestic product, and domestic wood production. Kukrety *et al*. (2013) evaluated the current Red Sanders wood trade in southern India using a SWOT-analytic hierarchy process (AHP) framework. Bit and Banerjee (2014) stated that the import of forestry-based products is increasing in terms of volume, value, and unit prices. Buongiorno (2016) conducted a study on gravity models of forest product trade, while Kolo and Tzanova (2017) focused on forecasting German forest product trade using a vector error correction model. Khosravi *et al*. (2018) examined the level of international trade and intra-industry trade as two indices of globalization and incorporated them into the import demand functions of various wood product categories in Iran. Bayram (2020) used the Entropy-TOPSIS methodology to evaluate the economic contribution of forest product trade in Turkey. Vu *et al*. (2020) analyzed the determinants of Vietnam's wood products trade using a gravity model. The researchers found that economic size, distance, and level of openness of the economy were significant determinants. Adhikari *et al*. (2022) utilized time-series modeling to examine the effects of foreign remittances on timber imports.

The literature review highlights the absence of identification and prioritization of factors influencing wood import decisions in the previous studies. It is challenging to determine which factors are more important than others. However, multicriteria decision-making methods can be employed to ascertain the most significant factors. One of the most popular and widely practiced multicriteria decision-making methods is the AHP. The AHP method involves creating a hierarchy of factors, sub-factors, and alternatives and comparing their relative importance through pairwise comparisons. Decision-makers assign weights to each decision element and use them to prioritize different options (Oblak *et al*., 2017). One of the key benefits of using the AHP is that it allows decision-makers to incorporate their expertise and judgment into the decision-making process. Furthermore, it is flexible and adaptable to different contexts and allows for easy updating of preferences. The AHP method is very useful in situations where decision-making involves multiple factors that are difficult to quantify or compare directly (Bhutta and Huq, 2002; Ishizaka and Labib, 2009).

Decision-making processes are often influenced by uncertainties and inaccurate information sources. To address these issues, the AHP method can be equipped with the fuzzy set theory. The Pythagorean fuzzy set has emerged as a powerful tool for incorporating fuzziness into the AHP. It provides a new way to model uncertain information by incorporating degrees of membership, non-membership, and indeterminacy. This allows decision-makers to express their preferences in a more nuanced way. The interval-valued Pythagorean fuzzy set is a generalization of the Pythagorean fuzzy set. It assigns an interval instead of a precise value to each element. The interval width provides additional information about the level of uncertainty associated with each element (Milošević *et al*., 2023).

The decision-making process regarding the importation of wood materials requires careful evaluation of multiple factors. There is a lack of research on the most important factors that influence this decision, and fuzzy decision-making methods have not been applied to this topic. To address this gap in the literature, this study uses the interval-valued Pythagorean fuzzy AHP method to identify and analyze factors influencing wood import decisions. This study makes a novel contribution to the field by being the first to prioritize the key factors related to the wood import process. The results of the current study provide a valuable guide to decision-makers to navigate the complexity of wood imports more effectively.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Interval-valued Pythagorean fuzzy set
2.1. Pitagorin neizraziti skup s intervalnim vrijednostima

The fuzzy set theory enables working with imprecise data and making effective decisions, even when exact values are unattainable (Sorkheh *et al*., 2018). The Pythagorean fuzzy set is a notable fuzzy extension characterized by membership degrees ($\mu_{\tilde{P}}(x)$) and non-membership degrees ($\nu_{\tilde{P}}(x)$). Unlike the ordinary fuzzy set, the Pythagorean fuzzy set allows the sum to exceed one. However, the sum of their squares is at most one (Zhang and Xu, 2014). The interval-valued Pythagorean fuzzy set builds upon the Pythagorean fuzzy set. This fuzzy set uses a pair of intervals to represent membership and non-membership degrees. The interval-valued Pythagorean fuzzy set offers a more powerful approach to modeling imprecise information. This fuzzy set is formally defined as presented in Eq. (1).

$$\tilde{P}=\left\{\langle x,[\mu_{\tilde{P}_L}(x),\mu_{\tilde{P}_U}(x)],[v_{\tilde{P}_L}(x),v_{\tilde{P}_U}(x)]\rangle ;x\epsilon X\right\} \quad (1)$$

The values of the parameters are between zero and one. Indeterminacy degrees are computed using Eq. (2) (Wu *et al*., 2019).

$$\pi_{\tilde{P}}(x)=\left[\sqrt{1-\left(\mu_{\tilde{P}_U}(x)\right)^2-\left(v_{\tilde{P}_U}(x)\right)^2},\ \sqrt{1-\left(\mu_{\tilde{P}_L}(x)\right)^2-\left(v_{\tilde{P}_L}(x)\right)^2}\right] \quad (2)$$

The following equations elucidate the basic algebraic operations applied to two interval-valued Pythagorean fuzzy numbers (Yanmaz *et al*., 2020).

$$\tilde{A}\oplus\tilde{B}=\left(\left[\sqrt{\left(\mu_A^L\right)^2+\left(\mu_B^L\right)^2-\left(\mu_A^L\right)^2\left(\mu_B^L\right)^2},\ \sqrt{\left(\mu_A^U\right)^2+\left(\mu_B^U\right)^2-\left(\mu_A^U\right)^2\left(\mu_B^U\right)^2}\right],\left[v_A^L v_B^L, v_A^U v_B^U\right]\right) \quad (3)$$

$$\tilde{A}\otimes\tilde{B}=\left(\left[\mu_A^L\mu_B^L,\mu_A^U\mu_B^U\right],\left[\sqrt{\left(v_A^L\right)^2+\left(v_B^L\right)^2-\left(v_A^L\right)^2\left(v_B^L\right)^2},\ \sqrt{\left(v_A^U\right)^2+\left(v_B^U\right)^2-\left(v_A^U\right)^2\left(v_B^U\right)^2}\right]\right) \quad (4)$$

$$\lambda\tilde{A}=([\sqrt{1-(1-\left(\mu_A^L\right)^2)^\lambda},\sqrt{1-(1-\left(\mu_A^U\right)^2)^\lambda}],[\left(v_A^L\right)^\lambda,\left(v_A^U\right)^\lambda]) \quad (5)$$

$$\tilde{A}^\lambda=([\left(\mu_A^L\right)^\lambda,\left(\mu_A^U\right)^\lambda],[\sqrt{1-(1-\left(v_A^L\right)^2)^\lambda},\sqrt{1-(1-\left(v_A^U\right)^2)^\lambda}]) \quad (6)$$

2.2 Interval-valued Pythagorean fuzzy analytic hierarchy process
2.2. Pitagorin neizraziti analitički hijerarhijski proces s intervalnim vrijednostima

The AHP is a widely used decision-making tool that helps individuals and organizations solve complex decision problems. This method involves four main steps. Firstly, the decision problem is hierarchically structured. Secondly, pairwise comparisons are made using a nine-point scale to create comparison matrices showing decision-makers' preferences. Thirdly, inconsistencies in comparisons are identified and corrected. Finally, the importance of decision elements is determined by normalizing the matrices and calculating row averages (Özşahin *et al*., 2019). Making decisions becomes more difficult when decision-makers' preferences are uncertain or subjective. Decision-makers often prefer to use linguistic terms to express their preferences. Hence, various fuzzy logic-based decision-making methods have been developed to handle uncertain judgments. The interval-valued Pythagorean fuzzy AHP method enables decision-makers to make more flexible and nuanced judgments. Some remarkable studies that have utilized the Pythagorean fuzzy AHP can be listed as follows: landfill site selection (Karasan *et al*., 2019), solar panel manufacturer selection (Seker and Kahraman, 2021), spaceport selection (Demiralay *et al*., 2022), pandemic hospital site selection (Boyacı and Şişman, 2022), building smartness assessment (Milošević *et al*., 2023), and assessment of biomass energy barriers (Shahzad *et al*., 2023). The interval-valued Pythagorean fuzzy AHP procedure considered in this study is as follows:

Step 1: Factors are compared with each other using Table 1 to create pairwise comparison matrices.

The evaluation scale helps decision-makers assign importance to factors through pairwise comparisons. This scale has linguistic terms corresponding to numerical values. Decision-makers use these linguistic terms to indicate how much more important factor *i* is compared to factor *j*. Once a linguistic term is selected, it is translated into a corresponding interval-valued Pythagorean fuzzy number. These fuzzy numbers represent decision-makers' judgments in a quantitative form, enabling numerical calculations.

Step 2: Each matrix consistency is assessed by applying Eq. (7). Should the *CR* index surpass 0.10, responders are required to reevaluate their decisions.

$$CR = \frac{\left(\frac{\lambda_{max} - n}{n-1}\right)}{RC} \quad (7)$$

Here, λ_{max} refers to the maximum eigenvalue. The table of the *RC* indexes can be seen in Saaty (1980). The consistency of each matrix is evaluated using crisp score indexes. These values are determined by matching the linguistic terms with Saaty's scale (Karasan *et al*., 2019). For example, the linguistic term "absolutely more important" corresponds to a value of 9 according to Saaty's scale. The consistency ratio is determined by adhering to the traditional AHP framework.

Step 3: Difference matrices are derived using Eqs. (8) and (9).

$$d_{ik_L} = \mu^2_{ik_L} - v^2_{ik_U} \quad (8)$$

$$d_{ik_U} = \mu^2_{ik_U} - v^2_{ik_L} \quad (9)$$

Step 4: Interval multiplicative matrices are derived using the following equations:

$$s_{ik_L} = \sqrt{1000^{d_{ik_L}}} \quad (10)$$

$$s_{ik_U} = \sqrt{1000^{d_{ik_U}}} \quad (11)$$

Step 5: Indeterminacy values are obtained using Eq. (12).

$$\tau_{ik} = 1 - (\mu^2_{ik_U} - \mu^2_{ik_L}) - (v^2_{ik_U} - v^2_{ik_L}) \quad (12)$$

Step 6: Weight matrices are created in accordance with the following equation:

$$t_{ik} = \left(\frac{s_{ik_L} + s_{ik_U}}{2}\right)\tau_{ik} \quad (13)$$

Step 7: Weights are obtained using Eq. (14).

$$w_i = \frac{\sum_{k=1}^{m} t_{ik}}{\sum_{i=1}^{m}\sum_{k=1}^{m} t_{ik}} \quad (14)$$

2.3 Decision-making framework
2.3. Okvir za donošenje odluka

The demand for wood and wood products has increased globally in recent years, resulting in a surge in wood imports in many countries. Wood import decisions are influenced by various factors, including price, wood species, and demand trends. Recognizing the significance of these factors and comprehending how they influence the decision-making process are paramount for decision-makers to allocate resources, time, and attention efficiently and to make well-informed and strategically effective decisions. In this study, the key factors affecting wood import decisions are analyzed using the interval-valued Pythagorean fuzzy AHP method. The

Table 1 Evaluation scale (Seker and Kahraman, 2021)
Tablica 1. Skala ocjenjivanja (Seker i Kahraman, 2021.)

Linguistic term *Lingvistički pojam*	**Interval-valued Pythagorean fuzzy number** *Pitagorin neizraziti broj s intervalnom vrijednošću*			
	μ_L	μ_U	v_L	v_U
Absolutely less important / *apsolutno manje važno*	0.03	0.16	0.74	0.87
Much less important / *dosta manje važno*	0.12	0.25	0.65	0.78
Less important / *manje važno*	0.21	0.34	0.56	0.69
Slightly less important / *malo manje važno*	0.30	0.43	0.47	0.60
Equally important / *jednako važno*	0.38	0.51	0.38	0.51
Slightly more important / *malo važnije*	0.47	0.60	0.30	0.43
More important / *više važno*	0.56	0.69	0.21	0.34
Much more important / *dosta važnije*	0.65	0.78	0.12	0.25
Absolutely more important / *apsolutno važnije*	0.74	0.87	0.03	0.16

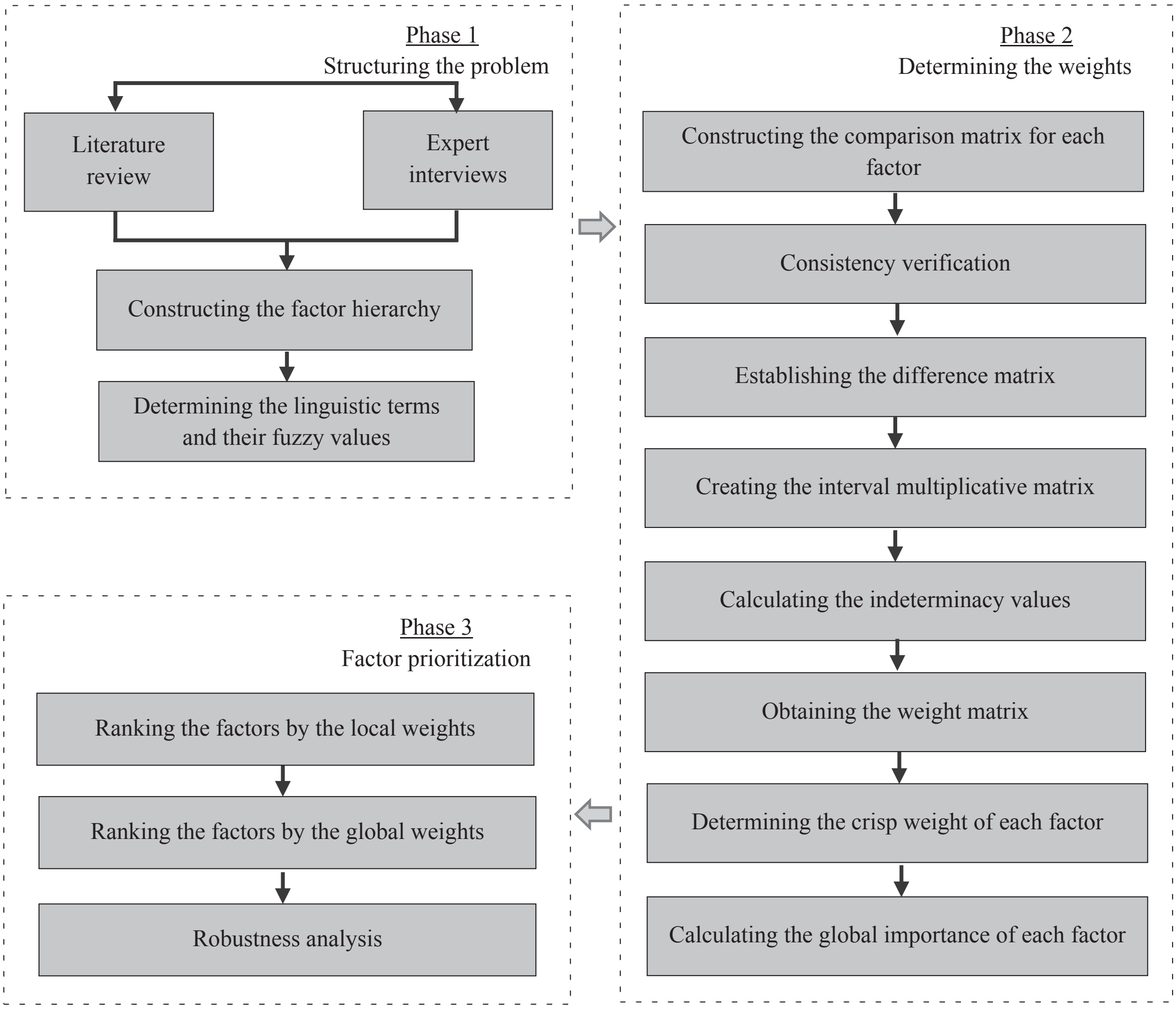

Figure 1 Steps of the present study
Slika 1. Koraci u ovoj studiji

results of the study are supported by a robustness analysis. The steps of this study are shown in Figure 1.

The research was conducted in Turkey. The geographical, economic, and industrial characteristics of the country make it a compelling case for analyzing wood import decisions. Turkey serves as a significant trade hub, linking Europe, Asia, and the Middle East. Its proximity to wood-exporting regions impacts its import patterns and decision-making processes. The construction, furniture, and paper industries in Turkey have experienced substantial growth, leading to a surge in demand for wood. Since domestic forestry production cannot fully meet this demand, imports play a crucial role in maintaining supply chain continuity. The increasing industrial demand makes strategic import decisions essential for meeting the need (Gültekin *et al*., 2009; Bayram, 2020). The insights from this study can guide decision-makers in managing wood imports.

The application of the interval-valued Pythagorean fuzzy AHP method requires input data from decision-makers to rank decision elements. Therefore, an expert team was formed. The selection of team members is based on the following criteria: (i) advanced education (preferably at the postgraduate level), (ii) a minimum of five years of relevant experience, (iii) research publications related to the study topic; and (iv) previous involvement in multicriteria decision-making research. For multicriteria decision-making methods, there are no strict guidelines regarding the number of respondents required. Since the AHP is not a methodology based on statistical principles, it can be effectively applied with a small sample size. The method is technically sound and does not necessitate a large number of participants for its implementation (Ahmadi *et al.*, 2015). Hence, ten experts were consulted in the study. The expert panel ensured balanced representation from both academia and industry, comprising specialists in supply chain management, procurement, manufacturing, and trade.

Several factors were discovered from the literature (Gültekin *et al*., 2009; Limaei *et al*., 2011; Kukrety *et al.*, 2013; Bit and Banerjee, 2014; Khosravi *et al.*, 2018; Bayram, 2020; Vu *et al.*, 2020). The list of factors obtained from the literature was refined and ex-

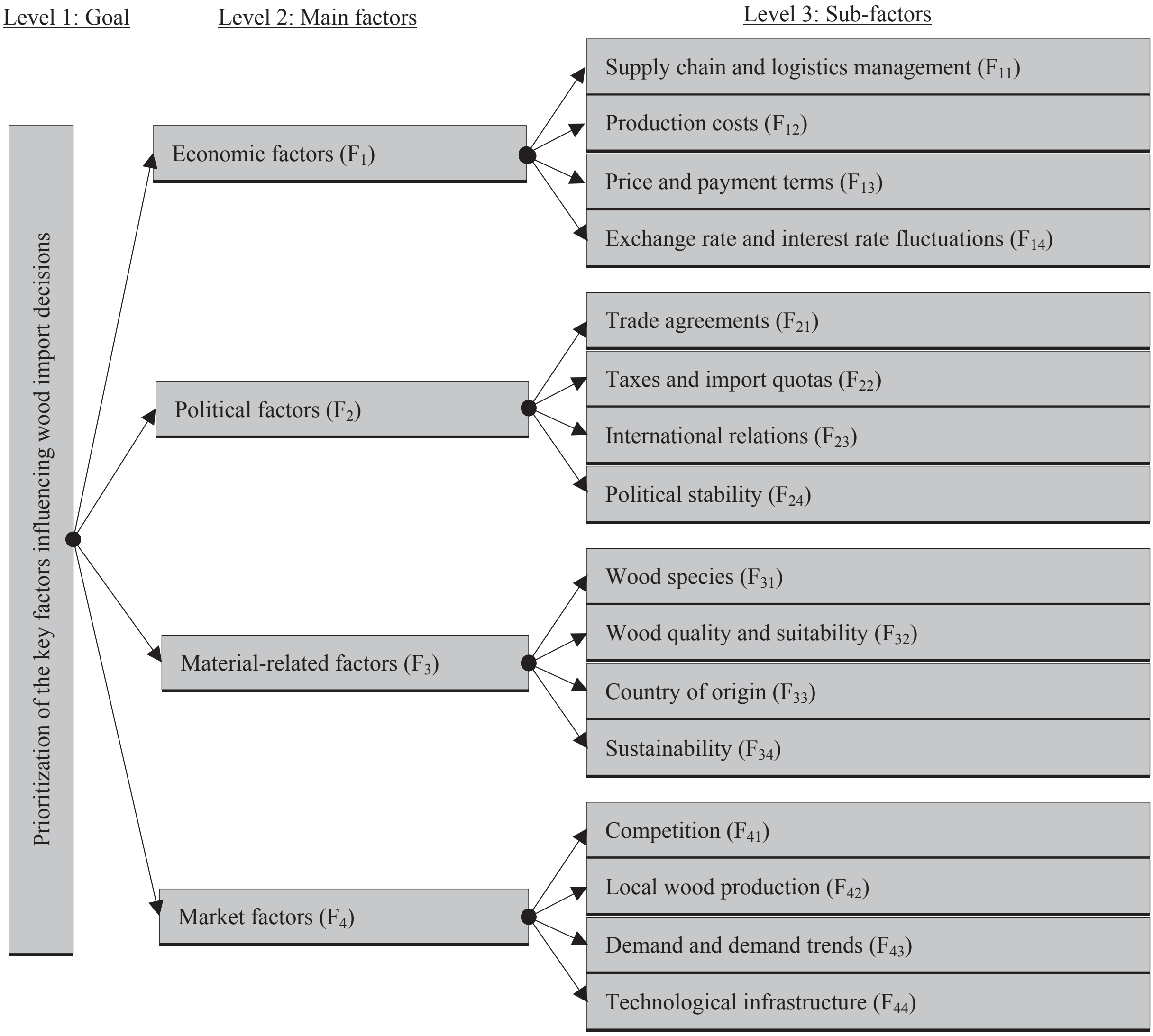

Figure 2 Proposed decision tree
Slika 2. Predloženo stablo odlučivanja

panded by the team. The final hierarchy of factors was predominantly shaped by expert input. The hierarchical structure of the problem was devised with one goal, four main factors, and sixteen sub-factors. Figure 2 illustrates the hierarchical structure devised in the study.

The main factors determined for the problem are "economic factors", "political factors", "material-related factors", and "market factors". The sub-factors of "economic factors" are identified as "supply chain and logistics management", "production costs", "price and payment terms", and "exchange rate and interest rate fluctuations". The sub-factors of "political factors" are defined as "trade agreements", "taxes and import quotas", "international relations", and "political stability". The sub-factors of "material-related factors" are identified as "wood species", "wood quality and suitability", "country of origin", and "sustainability". Lastly, the sub-factors of "market factors" are determined as "competition", "local wood production", "demand and demand trends", and "technological infrastructure".

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The experts in the team were called upon to express their preference between every pair of factors. The research was conducted over a two-month period, from October to November 2023. The completion of the fuzzy AHP questionnaires relies on the utilization of the verbal labels presented in Table 1 (Seker and Kahraman, 2021). The consensus-building process is applied to execute collaborative decision-making. It is carried out over three rounds. The collected responses are analyzed to identify common themes and points of disagreement. In the subsequent round, the experts review the group's feedback and reassess their opinions. The final stage involves reviewing the collected input to confirm the areas of consensus. The linguistic preferences expressed by the experts are converted into the corresponding interval-valued Pythagorean fuzzy numbers. The main factors are assessed in relation to the goal, and the sub-fac-

Table 2 Fuzzy comparison matrix for the main factors
Tablica 2. Neizrazita matrica usporedbe za glavne čimbenike

Factor	F_1	F_2	F_3	F_4
F_1	⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.47, 0.60], [0.30, 0.43]⟩	⟨[0.56, 0.69], [0.21, 0.34]⟩
F_2		⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.47, 0.60], [0.30, 0.43]⟩	⟨[0.47, 0.60], [0.30, 0.43]⟩
F_3			⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.47, 0.60], [0.30, 0.43]⟩
F_4				⟨[0.38, 0.51], [0.38, 0.51]⟩

Table 3 Fuzzy comparison matrix for the “economic factors” group
Tablica 3. Neizrazita matrica usporedbe za skupinu ekonomskih čimbenika

Factor	F_{11}	F_{12}	F_{13}	F_{14}
F_{11}	⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.56, 0.69], [0.21, 0.34]⟩	⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.65, 0.78], [0.12, 0.25]⟩
F_{12}		⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.30, 0.43], [0.47, 0.60]⟩	⟨[0.47, 0.60], [0.30, 0.43]⟩
F_{13}			⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.56, 0.69], [0.21, 0.34]⟩
F_{14}				⟨[0.38, 0.51], [0.38, 0.51]⟩

Table 4 Fuzzy comparison matrix for the “political factors” group
Tablica 4. Neizrazita matrica usporedbe za skupinu političkih čimbenika

Factor	F_{21}	F_{22}	F_{23}	F_{24}
F_{21}	⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.30, 0.43], [0.47, 0.60]⟩	⟨[0.47, 0.60], [0.30, 0.43]⟩	⟨[0.21, 0.34], [0.56, 0.69]⟩
F_{22}		⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.65, 0.78], [0.12, 0.25]⟩	⟨[0.30, 0.43], [0.47, 0.60]⟩
F_{23}			⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.03, 0.16], [0.74, 0.87]⟩
F_{24}				⟨[0.38, 0.51], [0.38, 0.51]⟩

Table 5 Fuzzy comparison matrix for the “material-related factors” group
Tablica 5. Neizrazita matrica usporedbe za skupinu čimbenika povezanih s materijalom

Factor	F_{31}	F_{32}	F_{33}	F_{34}
F_{31}	⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.47, 0.60], [0.30, 0.43]⟩	⟨[0.74, 0.87], [0.03, 0.16]⟩	⟨[0.56, 0.69], [0.21, 0.34]⟩
F_{32}		⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.65, 0.78], [0.12, 0.25]⟩	⟨[0.47, 0.60], [0.30, 0.43]⟩
F_{33}			⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.38, 0.51], [0.38, 0.51]⟩
F_{34}				⟨[0.38, 0.51], [0.38, 0.51]⟩

Table 6 Fuzzy comparison matrix for the “market factors” group
Tablica 6. Neizrazita matrica usporedbe za skupinu tržišnih čimbenika

Factor	F_{41}	F_{42}	F_{43}	F_{44}
F_{41}	⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.47, 0.60], [0.30, 0.43]⟩	⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.65, 0.78], [0.12, 0.25]⟩
F_{42}		⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.21, 0.34], [0.56, 0.69]⟩	⟨[0.56, 0.69], [0.21, 0.34]⟩
F_{43}			⟨[0.38, 0.51], [0.38, 0.51]⟩	⟨[0.74, 0.87], [0.03, 0.16]⟩
F_{44}				⟨[0.38, 0.51], [0.38, 0.51]⟩

tors are appraised in alignment with their relevant main factor. The matrices constructed for all the factors are presented in Tables 2-6. The consistency ratios calculated for the pairwise comparison matrices are: 0.04 for Table 2, 0.03 for Tables 3 and 4, and 0.05 for Tables 5 and 6. Since the resulting values are below 0.10, the pairwise comparisons are considered acceptable.

The weights of the main factors are determined based on the calculation procedure of the interval-valued Pythagorean fuzzy AHP and are presented in Figure 3. According to the obtained results, “economic factors” (0.361) and “political factors” (0.292) have the most significant impact on wood import decisions.

The weight values obtained for the sub-factors of “economic factors” are presented in Figure 4. The most significant sub-factor is “supply chain and logistics management” (0.450). This sub-factor has the most significant impact on the decision-making process. Supply chain and logistics management involve how efficiently and effectively an organization manages the movement of goods and materials. It can significantly impact a business’s ability to meet demand, reduce costs, and maintain product quality. Efficient and reliable management plays a crucial role in ensuring the timely and effective delivery of wood materials. The second most significant sub-factor is “price and payment terms” (0.295). The cost of wood materials and payment terms offered by suppliers influence the decision-making process. Importers should consider criteria such as pricing competitiveness, discounts, credit

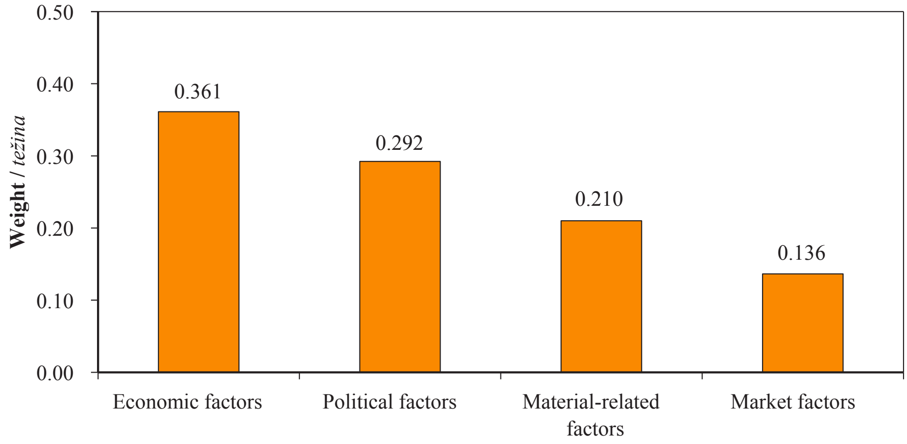

Figure 3 Modeling results for the main factors
Slika 3. Rezultati modeliranja za glavne čimbenike

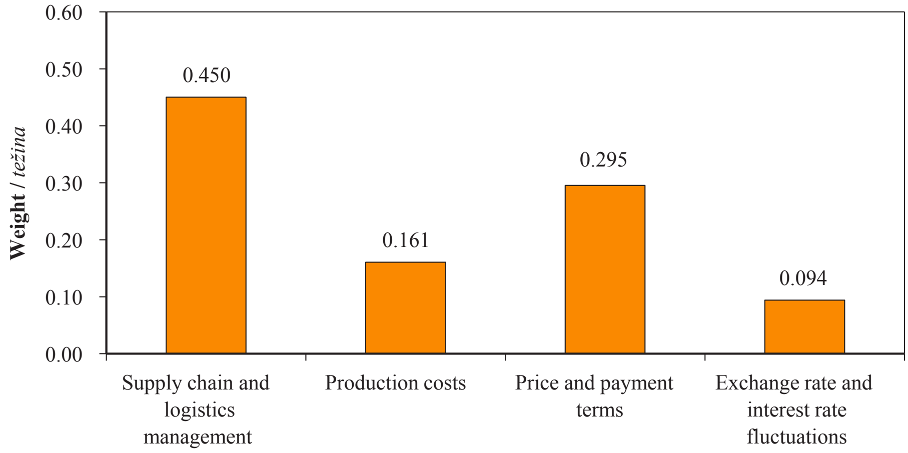

Figure 4 Modeling results for sub-factors of "economic factors"
Slika 4. Rezultati modeliranja za podčimbenike skupine ekonomskih čimbenika

terms, and payment flexibility when importing wood materials. "Production costs" is assigned a weight value of 0.161. "Exchange rate and interest rate fluctuations" has the lowest weight value of 0.094. Importers may monitor these fluctuations to mitigate potential risks but may not consider them as the primary determinants of their import decisions.

Figure 5 illustrates the weights for the "political factors" group. According to the results, the sub-factor with the highest local importance is "political stability" (0.513). The high importance of "political stability" indicates that the experts place significant emphasis on the stability of the political environment in source countries. A stable political environment provides predictability and security, which are essential for the smooth operation of international trade. When a country's political situation is stable, it reduces the risk of disruptions or sudden policy changes that could impact the flow of wood imports. The second most significant sub-factor appears to be "taxes and import quotas" (0.295). Higher taxes and quotas can increase the cost of importing wood, which, in turn, can negatively affect the profitability of businesses. Importers may seek countries or regions with more favorable tax policies and fewer import restrictions to enhance their financial performance. "International relations" (0.066) has the least impact on the decision-making process. While "international relations" has some influence, it is not as critical as the other sub-factors.

When examining the weight values presented in Figure 6, it can be seen that "wood species" (0.518) is the most important sub-factor within the "material-related factors" group. This implies that the type of wood species is a critical factor that affects importers' decision-making process. Different wood species have varying properties such as durability, appearance, and workability. Importers may rank or sort specific wood species to meet the requirements of their customers or applications. The weight value of 0.298 obtained for "wood quality and suitability" indicates that this sub-factor is also a crucial aspect. Importers must ensure that imported wood materials meet specific quality standards and are suitable for their intended applications. This includes some considerations such as moisture content, grain pattern, and defects. "Country of origin" (0.081) is less important than the other sub-factors. Importers may con-

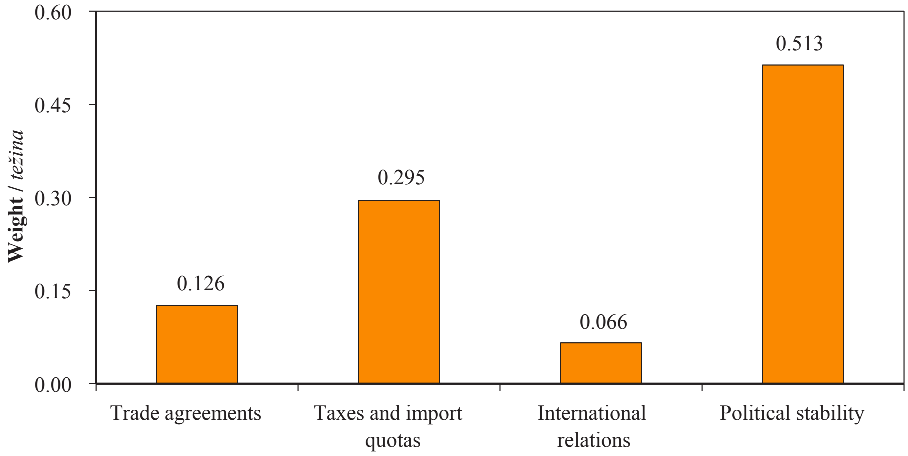

Figure 5 Modeling results for sub-factors of "political factors"
Slika 5. Rezultati modeliranja za podčimbenike skupine političkih čimbenika

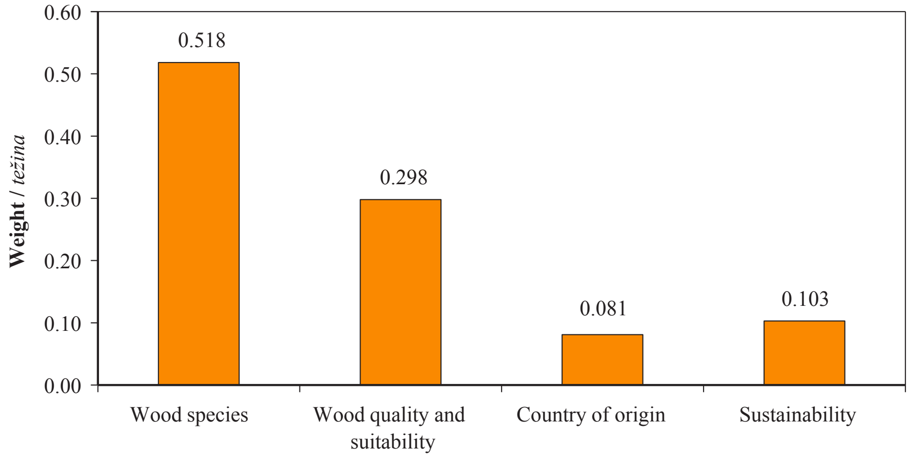

Figure 6 Modeling results for sub-factors of "material-related factors"
Slika 6. Rezultati modeliranja za podčimbenike skupine čimbenika povezanih s materijalom

sider the country of origin for logistical and market perception reasons, but it does not carry as much weight in the decision-making process.

The local importance of the sub-factors of "market factors" can be seen from Figure 7. It is observed that "demand and demand trends" (0.477) is the most significant sub-factor affecting wood import decisions. This indicates that the volume of wood demanded by the market and changes in demand trends are the most important considerations. Factors such as population growth, economic development, and shifts in consumer preferences could all impact the importance of "demand and demand trends". "Competition" (0.302) appears to be a relatively significant sub-factor. Competition in the wood import market can affect prices, availability, and market share. The weight value of 0.056 for "technological infrastructure" indicates that this sub-factor is less important compared to the other sub-factors.

The global weights are determined in order to prioritize the whole sub-factors based on their importance (Figure 8). These weights are obtained by synthesizing the local weights obtained from the pairwise comparisons of the main factors and their sub-factors. "Supply chain and logistics management" emerges as the most important factor, with a weight of 0.163, highlighting the significance of efficient and effective transportation and distribution networks. The ability to track shipments, ensure timely delivery, and manage any potential disruptions is crucial for ensuring a successful import process. "Political stability" is ranked second with a weight of 0.150, emphasizing the importance of a stable political environment in facilitating smooth trade operations. Political instability can lead to uncertain and unpredictable conditions that can negatively impact business operations. A stable political environment can help ensure consistent and reliable trade relationships. "Wood species" and "price and payment terms" are also identified as important factors, with respective weights of 0.109 and 0.107. Different species of wood have different properties such as strength, durability, and aesthetic appeal. Choosing the right species of wood is crucial for ensuring customer satisfaction and the longevity of the final product. On the other hand, the cost of wood can vary widely depending on a range of factors, including the country of origin, wood quality, and availability. It is

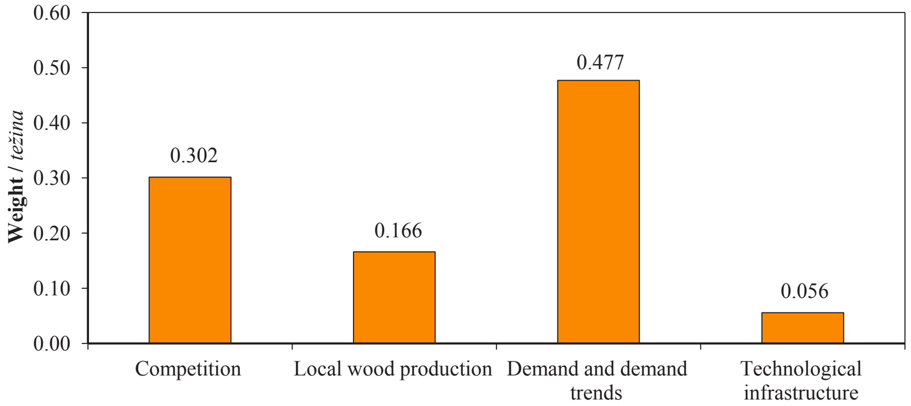

Figure 7 Modeling results for sub-factors of "market factors"
Slika 7. Rezultati modeliranja za podčimbenike skupine tržišnih čimbenika

important to negotiate favorable payment terms such as reasonable pricing and flexible payment options to ensure a profitable and sustainable business. "Taxes and import quotas" is also a significant factor with a weight of 0.086. It can impact the cost and availability of wood materials and can affect the overall profitability of a business. "Demand and demand trends", "wood quality and suitability", and "production costs" are other significant factors.

Sensitivity, validity, and comparative analyses are frequently used to validate model results and assess output changes (Valipour *et al*., 2018; Karasan *et al*., 2019). Hence, a validation analysis is carried out using the ordinary fuzzy and crisp environment with the same method. Subsequently, the BWM (best worst method) and FUCOM (full consistency method) methods are employed to compare the research results. The pairwise comparisons are adapted to align with the specific requirements of these crisp methods. The BWM analysis focuses on comparisons between the best and worst factors with the others, and the FUCOM analysis applies a sequential comparison structure based on the factors. Mathematical details of the BWM and FUCOM methods can be found in Rezaei (2015) and Pamučar *et al*. (2018). Lastly, a sensitivity analysis is conducted by examining four different scenarios. In these scenarios, F1, F2, F3, and F4 represent analyses where the weight of each main factor is individually increased by 25 %. The results obtained are presented in Figure 9.

According to the sensitivity analysis results, "supply chain and logistics management" consistently emerges as the most influential factor across all the scenarios. "Political stability" is another important fac-

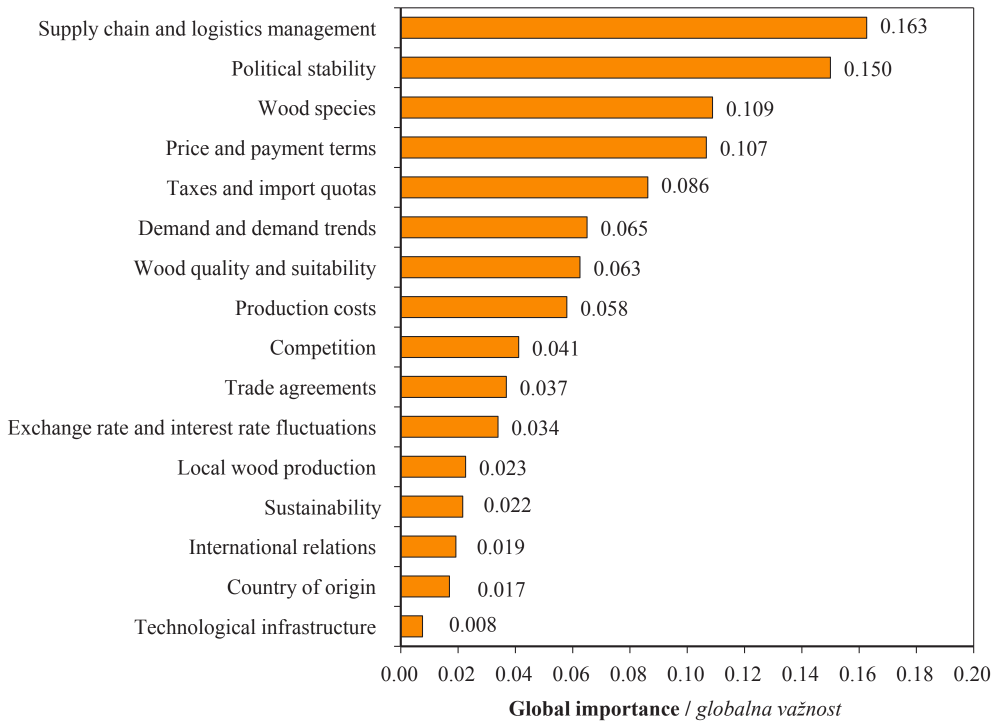

Figure 8 Global weights calculated for sub-factors
Slika 8. Izračunane globalne važnosti podčimbenika

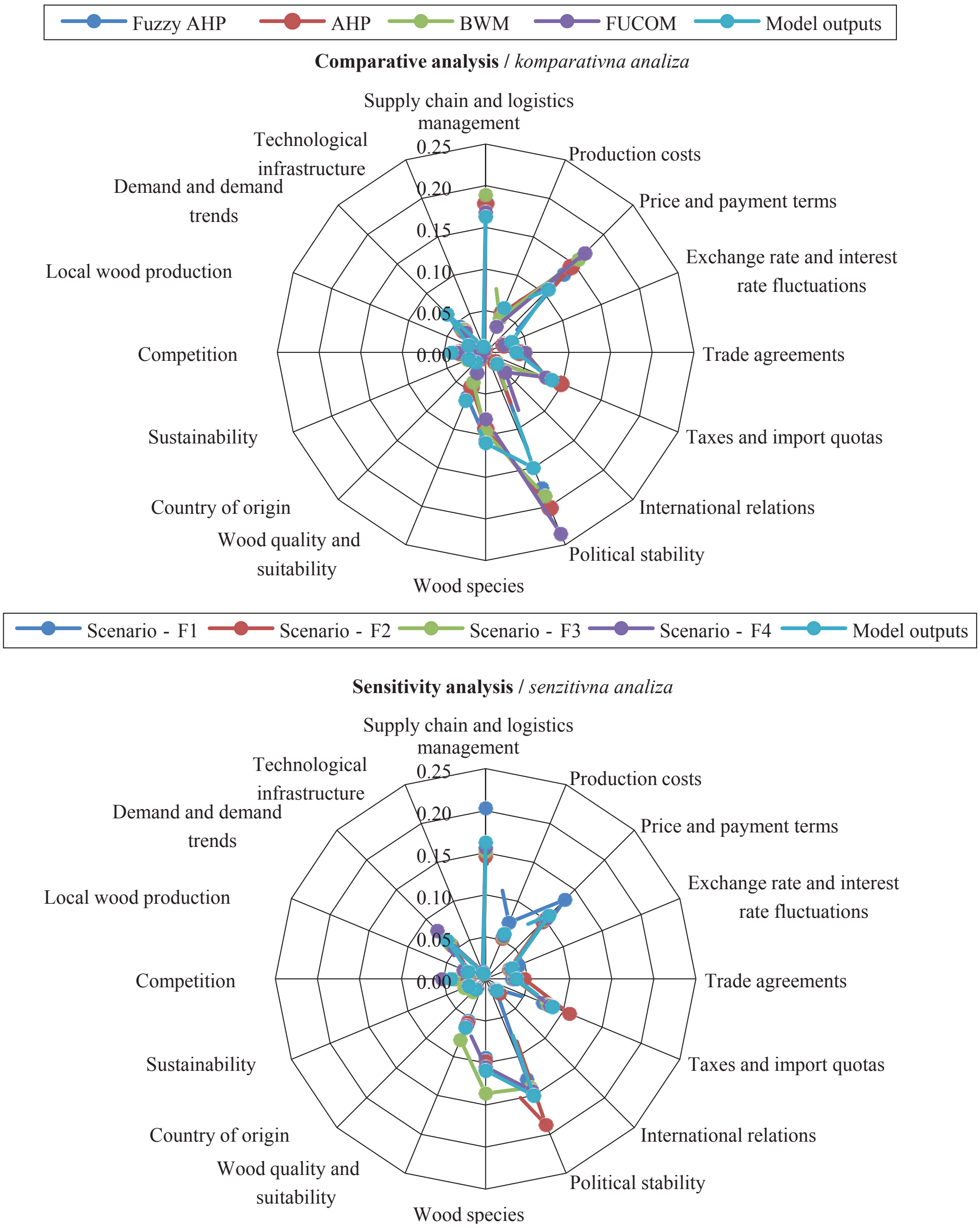

Figure 9 Robustness analysis results
Slika 9. Rezultati robusne analize

tor, holding the top rank in scenario F2 and showing strong stability with a consistent second-place ranking in the scenarios. "Price and payment terms" and "wood species" also prove to be significant, often appearing in the top three or four ranks across the scenarios. Price dynamics and the characteristics of wood particularly influence outcomes in scenarios F1 and F3. The results are highly consistent across the scenarios. Although the weights assigned to the factors by the methods vary, the overall ranking position of the factors tends to remain consistent. The interval-valued Pythagorean fuzzy AHP stands out for its ability to simultaneously consider membership, non-membership, and indeterminacy. It offers a more nuanced perspective compared to the other methods. These advantages make it a valuable tool for decision-making in complex situations. The results of this study can present a roadmap to make informed decisions about wood imports, develop more effective policies, improve supply chain management, and ensure responsible sourcing practices.

4 CONCLUSIONS
4. ZAKLJUČAK

Wood is a highly sought-after commodity traded internationally to meet the global demand for building materials, furniture, and paper products. As the global wood import market continues to expand, importers must make informed import decisions. This study aims to identify and prioritize factors influencing wood import decisions. The study employs a multi-step approach that includes a literature review and expert interviews to identify decision factors. Through this process, sixteen sub-factors are identified and classified into four main factors. The interval-valued Pythagorean fuzzy AHP method is used to assign weights to the factors. According to the results, "economic factors" and "political factors" are the most important main factors. The sub-factors with the highest local importance are: "supply chain and logistics management" in the "economic factors" group, "political stability" in the "political factors" group, "wood species" in the "material-related factors" group, and "demand and demand trends" in the "market factors" group. Furthermore, the global priority of the sub-factors is obtained as follows: "supply chain and logistics management" (16.3 %), "political stability" (15 %), "wood species" (10.9 %), "price and payment terms" (10.7 %), "taxes and import quotas" (8.6 %), "demand and demand trends" (6.5 %), "wood quality and suitability" (6.3 %), "production costs" (5.8 %), "competition" (4.1 %), "trade agreements" (3.7 %), "exchange rate and interest rate fluctuations" (3.4 %), "local wood production" (2.3 %), "sustainability" (2.2 %), "international relations" (1.9 %), "country of origin" (1.7 %), "technological infrastructure" (0.8 %). The model's results allow decision-makers to determine the most important factors in the decision-making process.

The results of the current study have significant implications for businesses and policymakers. With a clear understanding of the key factors, these groups can make more informed choices about sourcing and purchasing wood. For businesses, the study can help identify which factors are most important in the decision-making process. This information can inform business sourcing strategies and supply chain management, ultimately leading to more efficient operations. For policymakers, the study can inform regulations and policies related to the trade, importation, and transportation of wood materials.

The decision model involves gathering expert opinions on the importance of each factor, performing interval-valued Pythagorean fuzzy AHP calculations, determining the importance weights of the factors, and analyzing the ranking results. It can be updated as new information or expert insights become available. The updating process involves incorporating new or revised factors, considering expert opinions, and recalculating the importance weights using the interval-valued Pythagorean fuzzy AHP method. This study provides valuable insights into the wood import process. However, there is a limitation: the challenge of applying the weighted factors to sectors outside the forest industry. The original set of factors and their assigned weights may not fully align with the specific requirements of sectors different from the forest industry. The decision model can be adapted to various contexts beyond the wood supply chain by adjusting the factors.

This research presents a unique and valuable contribution to the field, as it is the first study to rank the most important factors affecting wood import decisions and apply the fuzzy multicriteria decision-making technique to the problem. Specifically, the study stands out in the following ways: (i) identifying, classifying, and prioritizing the most important factors influencing wood import decisions; (ii) conducting a comprehensive analysis of the identified factors; (iii) accounting for uncertainties and indeterminacies in the wood import decision-making process; (iv) incorporating expert perspectives into the problem-solving process; (v) employing the interval-valued Pythagorean fuzzy set to solve the problem; and (vi) providing a valuable guide to decision-makers for making more informed and effective import decisions. In conclusion, this study makes a valuable contribution to the growing literature on import decisions. Further research can explore the interdependency among the identified factors via a fuzzy cognitive map.

5 REFERENCES
5. LITERATURA

1. Adhikari, R. K.; Poudyal, N. C.; Shrestha, A., 2022: The effect of foreign remittance on timber imports: Evidence from Nepal. Journal of Forest Research, 27 (5): 323-333. https://doi.org/10.1080/13416979.2022.2034228
2. Ahmadi, H.; Nilashi, M.; Ibrahim, O., 2015: Organizational decision to adopt hospital information system: An empirical investigation in the case of Malaysian public hospitals. International Journal of Medical Informatics, 84 (3): 166-188. https://doi.org/10.1016/j.ijmedinf.2014.12.004
3. Arabatzis, G.; Klonaris, S., 2009: An analysis of Greek wood and wood product imports: Evidence from the linear quadratic aids. Forest Policy and Economics, 11 (4): 266-270. https://doi.org/10.1016/j.forpol.2009.04.002
4. Bayram, B. Ç., 2020: Evaluation of forest products trade economic contribution by entropy-TOPSIS: case study of Turkey. BioResources, 15 (1): 1419-1429. https://doi.org/10.15376/biores.15.1.1419-1429
5. Bhutta, K. S.; Huq, F., 2002: Supplier selection problem: A comparison of the total cost of ownership and analytic hierarchy process approaches. Supply Chain Management, 7 (3): 126-135. https://doi.org/10.1108/13598540210436586
6. Bit, J.; Banerjee, S., 2014: Consumption of wood products and dependence on imports: A study on post-reform India. Foreign Trade Review, 49 (3): 263-290. https://doi.org/10.1177/0015732514539204
7. Boyacı, A. Ç.; Şişman, A., 2022: Pandemic hospital site selection: A GIS-based MCDM approach employing Pythagorean fuzzy sets. Environmental Science and Pollution Research, 29 (2): 1985-1997. https://doi.org/10.1007/s11356-021-15703-7
8. Buongiorno, J., 2016: Gravity models of forest products trade: Applications to forecasting and policy analysis.

Forestry, 89 (2): 117-126. https://doi.org/10.1093/forestry/cpw005
9. De Araujo, V. A.; Cortez-Barbosa, J.; Gava, M.; Garcia, J. N.; de Souza, A. J. D.; Savi, A. F.; Morales, E. A. M.; Molina, J. C.; Vasconcelos, J. S.; Christoforo, A. L.; Lahr, F. A. R., 2016: Classification of wooden housing building systems. BioResources, 11 (3): 7889-7901.
10. Demiralay, E.; Hasan Çopur, E.; Paksoy, T., 2022: Spaceport selection using a novel hybrid Pythagorean fuzzy AHP & TOPSIS based methodology: A case study of Turkey. Journal of Aeronautics and Space Technologies, 15 (1): 1-17.
11. Geng, A.; Ning, Z.; Zhang, H.; Yang, H., 2019: Quantifying the climate change mitigation potential of China's furniture sector: Wood substitution benefits on emission reduction. Ecological Indicators, 103 (159): 363-372. https://doi.org/10.1016/j.ecolind.2019.04.036
12. Gültekin, Y. S.; Kayacan, B.; Ok K., 2009: Investigation of timber demand of forest industry in Duzce province. Düzce University Journal of Forestry, 5 (2): 75-94.
13. Ishizaka, A.; Labib, A., 2009: Analytic hierarchy process and expert choice: Benefits and limitations. OR Insight, 22 (4): 201-220. https://doi.org/10.1057/ori.2009.10
14. Karasan, A.; Ilbahar, E.; Kahraman, C., 2019: A novel Pythagorean fuzzy AHP and its application to landfill site selection problem. Soft Computing, 23 (21): 10953-10968. https://doi.org/10.1007/s00500-018-3649-0
15. Khosravi, S.; Maleknia, R.; Adeli, K.; Mohseni, R.; Hodges, D. G., 2018: The effects of globalization on the imports of wood products in Iran. Journal of Forest Economics, 32: 116-122. https://doi.org/10.1016/j.jfe.2018.04.004
16. Kolo, H.; Tzanova, P., 2017: Forecasting the German forest products trade: A vector error correction model. Journal of Forest Economics, 26: 30-45. https://doi.org/10.1016/j.jfe.2016.11.001
17. Kukrety, S.; Dwivedi, P.; Jose, S.; Alavalapati, J. R. R., 2013: Stakeholder's perceptions on developing sustainable Red Sanders (*Pterocarpus santalinus* L.) wood trade in Andhra Pradesh, India. Forest Policy and Economics, 26: 43-53. https://doi.org/10.1016/j.forpol.2012.08.014
18. Limaei, S. M.; Heybatian, R.; Heshmatol Vaezin, S. M.; Torkman, J., 2011: Wood import and export and its relation to major macroeconomics variables in Iran. Forest Policy and Economics, 13 (4): 303-307. https://doi.org/10.1016/j.forpol.2011.03.001
19. Milošević, M. R.; Milošević, D. M.; Stević, D. M.; Kovačević, M., 2023: Interval valued Pythagorean fuzzy AHP integrated model in a smartness assessment framework of buildings. Axioms, 12 (3): 1-23. https://doi.org/10.3390/axioms12030286
20. Oblak, L.; Barčić, A. P.; Klarić, K.; Kuzman, M. K.; Grošelj, P., 2017: Evaluation of factors in buying decision process of furniture consumers by applying AHP method. Drvna industrija, 68 (5): 37-43. https://doi.org/10.5552/drind.2017.1625
21. Özşahin, Ş.; Singer, H.; Temiz, A.; Yildirim, İ., 2019: Selection of softwood species for structural and non-structural timber construction by using the analytic hierarchy process (AHP) and the multiobjective optimization on the basis of ratio analysis (MOORA). Baltic Forestry, 25 (2): 281-288. https://doi.org/10.46490/vol25iss2pp281
22. Pamučar, D.; Stević, Ž.; Sremac, S., 2018: A new model for determining weight coefficients of criteria in MCDM models: full consistency method (FUCOM). Symmetry, 10 (9): 393. https://doi.org/10.3390/sym10090393
23. Park, B.-H.; Kwon, S.-M.; Kwon, G.-J.; Jang, J.-H.; Kim, N.-H., 2010: Appearance pattern of figures in commercial domestic hardwoods (I). Journal of the Korean Wood Science and Technology, 38 (5): 391-398.
24. Rezaei, J., 2015: Best-worst multi-criteria decision-making method. Omega, 53: 49-57. https://doi.org/10.1016/j.omega.2014.11.009
25. Saaty, T. L., 1980: The analytic hierarchy process: Planning, priority setting, resource allocation. New York: McGraw-Hill.
26. Seker, S.; Kahraman, C., 2021: Socio-economic evaluation model for sustainable solar PV panels using a novel integrated MCDM methodology: A case in Turkey. Socio-Economic Planning Sciences, 77: 1-14. https://doi.org/10.1016/j.seps.2020.100998
27. Shahzad, K.; Lu, B.; Abdul, D.; Safi, A.; Umar, M.; Afridi, N. K., 2023: Assessment of biomass energy barriers towards sustainable development: Application of Pythagorean fuzzy AHP. Geological Journal, 58 (4): 1607-1622. https://doi.org/10.1002/gj.4680
28. Sorkheh, K.; Kazemifard, A.; Rajabpoor, S., 2018: A comparative study of fuzzy linear regression and multiple linear regression in agricultural studies: A case study of lentil yield management. Turkish Journal of Agriculture and Forestry, 42 (6): 402-411. https://doi.org/10.3906/tar-1709-57
29. Valipour, A.; Sarvari, H.; Tamošaitiene, J., 2018: Risk assessment in ppp projects by applying different mcdm methods and comparative results analysis. Administrative Sciences, 8 (4): 1-17. https://doi.org/10.3390/admsci8040080
30. Vu, T. T. H.; Tian, G.; Zhang, B.; Nguyen, T. V., 2020: Determinants of Vietnam's wood products trade: Application of the gravity model. Journal of Sustainable Forestry, 39 (5): 445-460. https://doi.org/10.1080/10549811.2019.1682011
31. Wu, M. Q.; Zhang, C. H.; Liu, X. N.; Fan, J. P., 2019: Green supplier selection based on DEA model in interval-valued Pythagorean fuzzy environment. IEEE Access, 7: 108001-108013. https://doi.org/10.1109/ACCESS.2019.2932770
32. Yanmaz, O.; Turgut, Y.; Can, E. N.; Kahraman, C., 2020: Interval-valued Pythagorean fuzzy EDAS method: An application to car selection problem. Journal of Intelligent & Fuzzy Systems, 38 (4): 4061-4077. https://doi.org/10.3233/jifs-182667
33. Zhang, X.; Xu, Z., 2014: Extension of TOPSIS to multiple criteria decision making with Pythagorean fuzzy sets. International Journal of Intelligent Systems, 29 (12): 1061-1078. https://doi.org/10.1002/int.21676

Corresponding address:

HİLAL SİNGER

Department of Industrial Engineering, Karadeniz Technical University, Kanuni Campus, 61080 Trabzon, TURKEY, e-mail: hilal.singer@hotmail.com, hilalsinger@ktu.edu.tr